Difference between the Fuijtsu-Patent and the Invention

The base of a bipolar transistor is located near the silicon surface for example in a depth of 0.3um. Crystal defects in the base cause recombination of the base current, which lowers the current amplification of the transistor - especially at low currents. To judge whether a high energy implantation is suited to produce high quality semiconductor devices it is necessary to have an eye on the crystal defect density near the surface, which has to be very low.

With the help of a simulation program for the implantation of ions into matter it is posssible to calculate the **number of displacements of target atoms per ion and per angstrom depth**. Doing this for 400keV, 1MeV and 6MeV ions into silicon one obtains the following graphs (Fig. 1, 2 and 3). The resulting displacement densities at the base depth (0.3um) are about 0.59, 0.23 and 0.049 displacements/ion/angstrom, respectively. Fig. 3 shows also the depths, where the displacement density is equal to the displacement densities at the base depth of the 400keV (3.22um) and 1MeV (2.47um) implantation, as well as the depth of the maximum displacement density (3.33 um).

During the **annealing process** the implanted doping atoms as well as the displaced target atoms were (re)integrated into the silicon lattice. But some atoms may not find a lattice site and can form a **crystal defect**. It can be assumed that there is a a fixed correlation between displacement density and obtained crystal defect density (for a certain implantation dose and annealing process).

Fig. 4 shows a REM picture of an angled cut of a piece of silicon, which was implantated by 6MeV phosphorus ions, annealed and etched to the make the crystal defects visible.

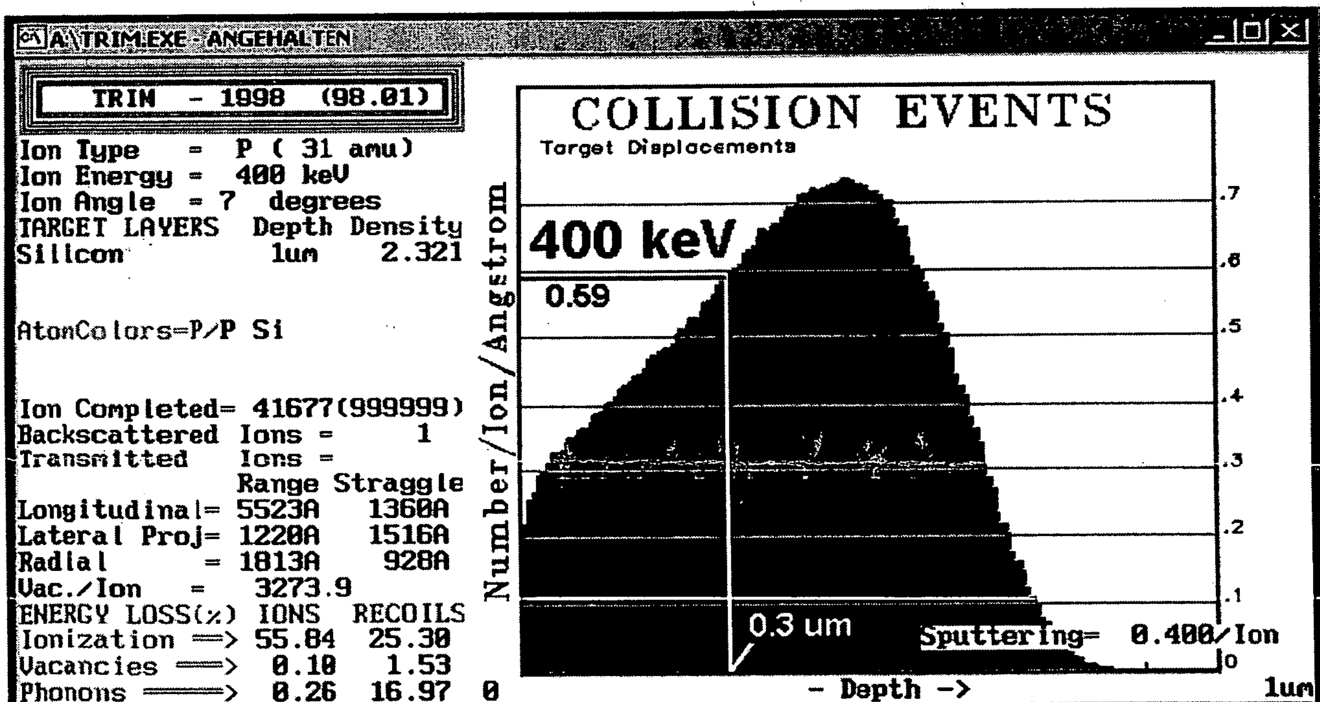

Fig. 1: Number of target displacements per ion and per angstrom for the implantation of 400keV phosphorus ions into silicon.
The displacement density in a base depth of 0.3um is 0.59 displacements/ion/angstrom.

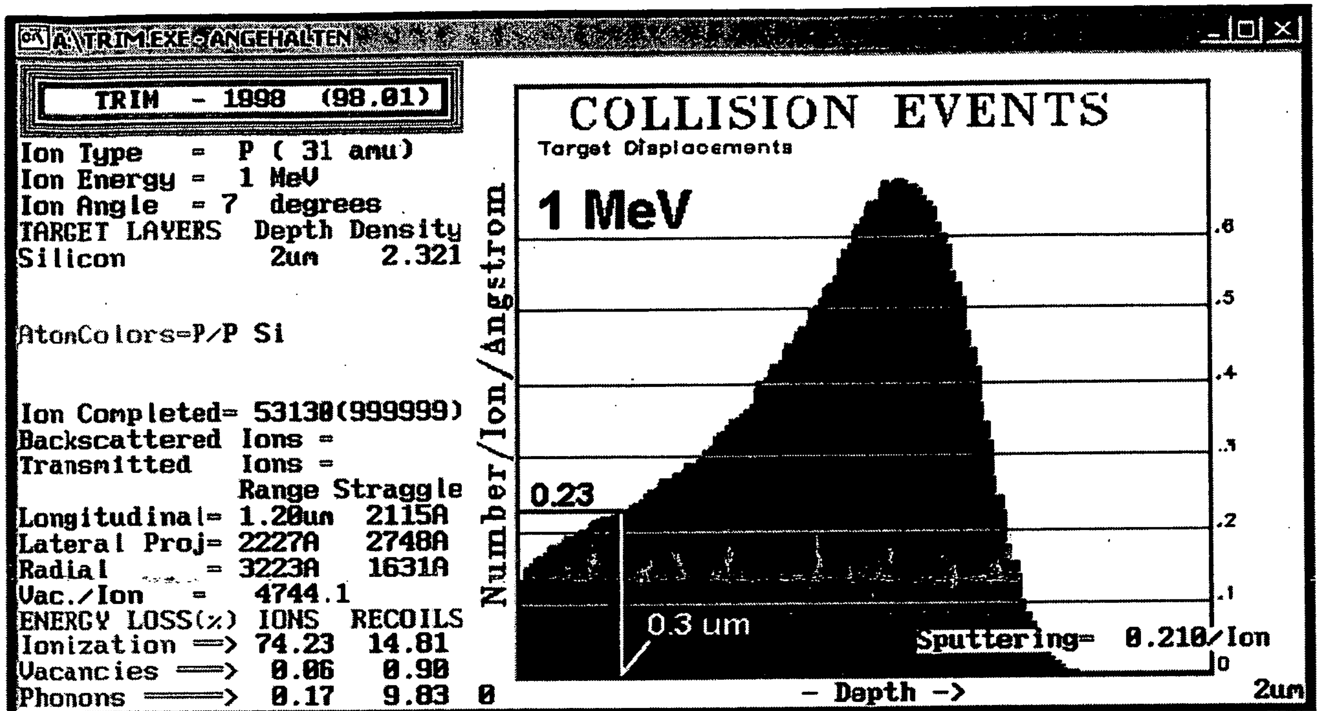

Fig. 2: Number of target displacements per ion and per angstrom for the implantation of 1MeV phosphorus ions into silicon.
The displacement density in a base depth of 0.3um is 0.23 displacements/ion/angstrom.

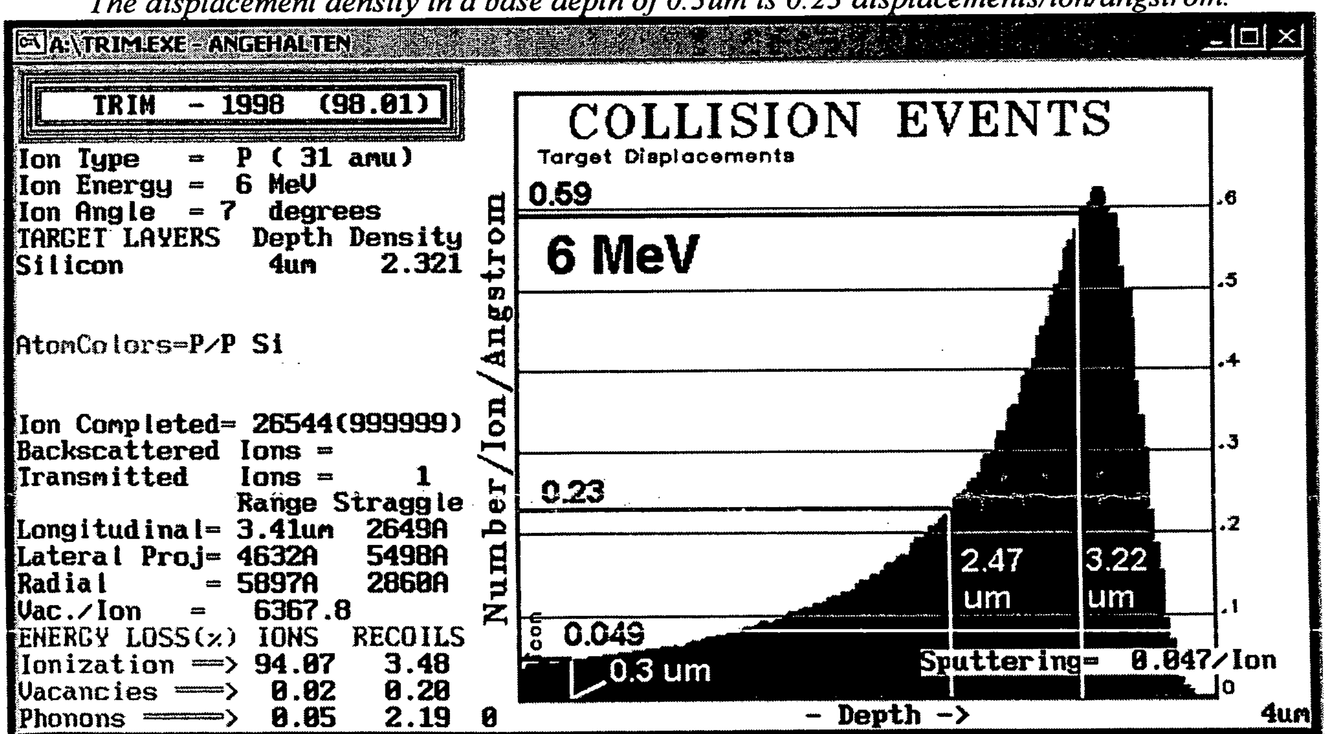

Fig. 3: Number of target displacements per ion and per angstrom for the implantation of 6MeV phosphorus ions into silicon.
The displacement density in a base depth of 0.3um is 0.049 displacements/ion/angstrom.
The same displacement densities which can be observed at 0.3um in a 400keV and a 1MeV implantation are obtained for a 6MeV implantation at depths of 3.22um and 2.47um, respectively.

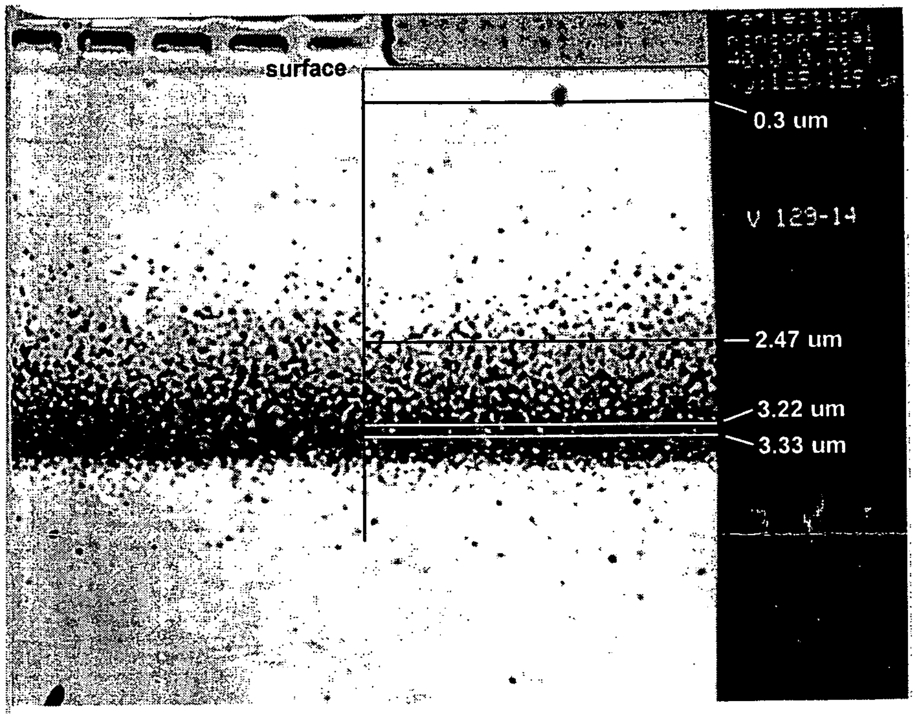

Fig. 4: REM picture of an angled polish of piece of silicon, which was implantated by 6MeV phosphorus ions, annealed and etched to make the crystal defects visible.

One can see, that there is a high crystal defect density at a depth of 3.33um, which is dropping towards the surface and towards the bulk of the substrate. Obviously a displacement density of 0.049 displacements/ion/angstrom at the base depth (for the applied implantation dose) is completely annealed. There are no crystal defects any more. This is not the case in depths of 3.22um and 2.47um, where the defect densities are representative for the base regions of a 400keV and a 1MeV implantation. There are a lot of crystal defects disturbing the silicon single crystal and preventing pn junctions from proper working with a high minority carrier lifetime. This is the reason why ion energies for the implantation of a N-well must be well above 1MeV to produce high quality semiconductor devices.